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Improved functional outcome and tuberosity healing in patients treated with fracture stems than nonfracture stems during shoulder arthroplasty for proximal humeral fracture: a meta-analysis and systematic review

James R. Onggo, MBBS (Hons)[a,b,*], Mithun Nambiar, MBBS, BMedSc[a,b], Jason D. Onggo, BEng, MD[a,c], Raphael Hau, MBBS, FRACS[a,d], Richard Pennington, BSc (Hons), MBBS, FRCSEd (Tr&Orth), FRACS, FAOrthA[a,d], Kemble K. Wang, MBBS, BMedSc, FRACS[a,b,e]

[a]*Department of Orthopaedic Surgery, Box Hill Hospital, Box Hill, VIC, Australia*
[b]*Faculty of Medicine, Nursing and Health Sciences, Monash University, Clayton, VIC, Australia*
[c]*Department of Orthopaedic Surgery, Tan Tock Seng Hospital, Singapore*
[d]*Epworth Eastern Hospital, Box Hill, VIC, Australia*
[e]*Department of Orthopaedic Surgery, Royal Children's Hospital, Parkville, VIC, Australia*

Background: Proximal humeral fractures are difficult injuries to treat and obtain satisfactory outcomes. For those treated with arthroplasty, humeral fracture stems have been popular due to better ability for reduction and fixation of tuberosities. This study aims to investigate the outcomes of fracture stems in shoulder arthroplasty for proximal humeral fracture and the comparison of outcomes between fracture vs. nonfracture stems.
Methods: A meta-analysis was conducted with a multidatabase search (PubMed, OVID, EMBASE, Medline) according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines on May 19, 2020. Data from all published literature meeting inclusion criteria were extracted and analyzed.
Findings: Eleven studies were included for analysis, including 383 hemiarthroplasties (HA) (294 fracture stems, 89 nonfracture stems) and 358 reverse total shoulder arthroplasties (RTSA) (309 fracture stems, 49 nonfracture stems). At the final follow-up, meta-analysis shows favorable overall ASES score in all fracture stem prosthesis (mean = 74.0, 95% confidence interval [CI]: 69.3-78.7), Constant-Murley score (mean = 67.2, 95% CI: 61.6-72.8), external rotation (mean difference [MD] = 7°, 95% CI: 3°-10°, $P < .001$), and forward flexion (MD = 17°, 95% CI: 10°-25°, $P < .001$). Pooled proportion (PP) of greater tuberosity healing (PP = 0.786, 95% CI: 0.686-0.886) was high, whereas all-cause revisions (PP = 0.034, 95% CI: 0.018-0.061) remained low. With the exception of RTSA scapular notching (PP = 0.109, 95% CI: 0.020-0.343), other complication metrics had PP of ≤0.023. In the 4 studies comparing fracture (138 HA, 54 RTSA) vs. nonfracture stems (89 HA, 49 RTSA), fracture stems had statistically significant better American Shoulder and Elbow Surgeons scores (MD = 14.29, 95% CI: 8.18-20.41, $P < .001$), external rotation (MD = 6°, 95% CI: 2°-9°, $P = .003$), forward flexion

Institutional review board approval was not required for this systematic review.

*Reprint requests: James R. Onggo, MBBS (Hons), Department of Orthopaedic Surgery, Box Hill Hospital, 8 Arnold Street, Box Hill, VIC 3128, Australia.
E-mail address: jamesonggo1993@hotmail.com (J.R. Onggo).

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(MD = 16°, 95% CI: 7°-24°, $P < .001$), and greater tuberosity healing (odds ratio = 2.20, 95% CI: 1.28-3.77, $P = .004$). There was no statistically significant difference in complications.
Conclusion: Fracture stems showed promising overall clinical outcomes with low complication rates in treating proximal humeral fractures. The use of fracture stems is also associated with greater chance of tuberosity healing compared with nonfracture stems. There is increasing evidence to suggest the superiority of fracture stems over nonfracture stems in clinical outcomes, while maintaining similar complication rates.
Level of evidence: Level III; Meta-Analysis/Systematic Review

Keywords: Shoulder arthroplasty; reverse total shoulder arthroplasty; shoulder hemiarthroplasty; fracture stems; proximal humeral fractures

Proximal humeral fractures (PHF) make up approximately 5%-6% of all fractures, with 71% occurring in patients older than 60 years and 76% occurring in females.[7,26] This rate increases to more than 10% of all fractures in patients 50-90 years of age.[8]

Treatment options for PHF include nonoperative management, internal fixation, or shoulder arthroplasty.[32] Shoulder hemiarthroplasty (HA) was first described for the treatment of PHF by Charles Neer in 1955.[29] Although this is a viable option for treating PHF, HA can be complicated by issues of tuberosity healing that can result in resorption, migration, and malunion.[3] Furthermore, HA can result in glenoid wear that is associated with worse functional outcomes.[33] Reverse total shoulder arthroplasty (RTSA) is becoming more common in the treatment of PHF, with a recent meta-analysis describing better clinical outcomes and fewer adverse events compared with HA.[1,32] The primary advantage of RTSA lies in the construct being less reliant on rotator cuff function and tuberosity healing. Potential complications of RTSA for PHF include instability, nonunion of tuberosities, pain, and reduced range of movement.[23] Tuberosity healing is associated with better functional outcome, in particular improved external rotation.[9,13] Nonunion of the tuberosities can result in weakness and also impingement symptoms.[16]

Superior results from fracture-specific stems are hypothesized to be primarily due to tuberosity healing. This is vital for restoring rotator cuff integrity, which is important for optimal functional results, particularly in HA.[2,12,17] Nonfracture stems may be suboptimal in the treatment of PHF for several reasons: (1) it increases the difficulty of anatomic repair of tuberosity fragments intraoperatively; (2) it may act as a barrier for bone healing;[2,3,12] and (3) it has poor rotational control in the meta-diaphysis in the setting of substantial metaphyseal bone loss in PHF.[23] In contrast, most fracture stems have design benefits that reduce the risk of tuberosity complications. These include low-profile stems with less proximal metal to allow better bony tuberosity contact, proximal bone-friendly coatings, medial stem offsets to provide more space for tuberosity positioning, and implant height markers and adjustments.[4,25,30] They also often have a longer stem length and a diaphyseal locking design to provide rotational stability for optimal bone healing.[6,37] The fracture stems in both HA and RTSA provide a platform for suturing and securing tuberosities to the proximal humerus, with the aim of improving union rates of these fragments, and are increasingly used in the PHF setting (Fig. 1).

As technology and patient demands evolve over the years, the use of arthroplasty for PHF has increased steadily, and it is imperative for these patients to receive the appropriate prosthesis for its indication.[20] An analysis is thus important to delineate the true benefits of fracture stems over nonfracture stems amidst inconsistent evidence, as well as to be able to provide statistical figures and information for patient education during the informed consenting process. The aim of this study was to compare the clinical and radiographic outcome of fracture and nonfracture stems in patients undergoing HA or RTSR for PHF.

Methods

Literature search

This meta-analysis was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses criteria.[28] A comprehensive multidatabase search (PubMed, OVID, Medline, EMBASE) was conducted from the date of database inception to May 19, 2020. The Medical Subject Headings and Boolean operators used for this search were as follows: (shoulder arthroplasty OR shoulder replacement OR shoulder hemiarthroplasty) AND (stem OR fracture stem). Identified articles and their corresponding references were reviewed and considered for inclusion according to the selection criteria.

Selection criteria

All articles of any study design, including both randomized controlled trials and nonrandomized studies on intervention efforts, reporting on the outcome of fracture stems, or comparing the outcomes of fracture vs. nonfracture stems in the treatment of PHF, were considered for inclusion. Fracture stems used for shoulder HA or RTSA were included. Non–English language studies, duplicate studies, non–peer reviewed studies, unpublished

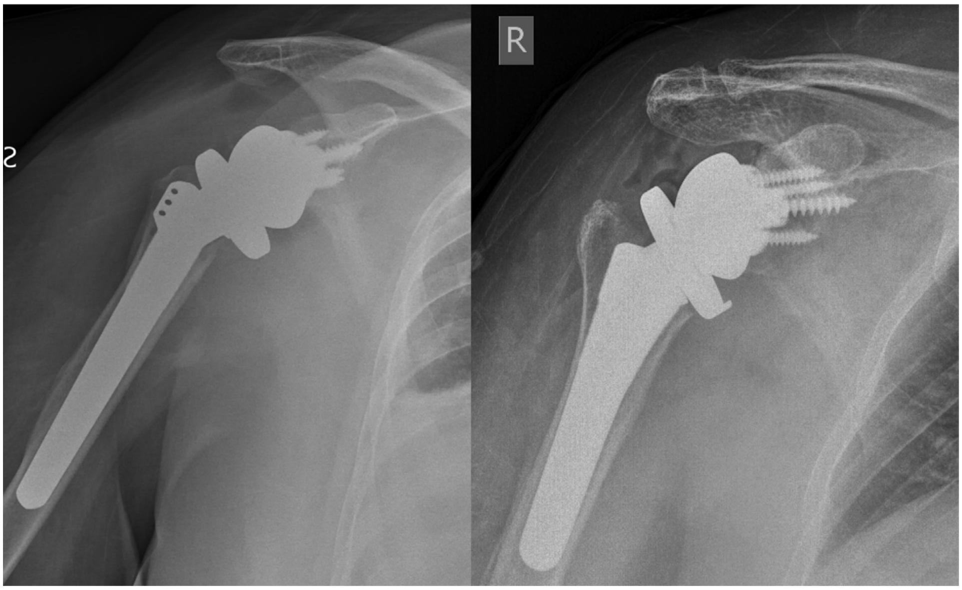

Figure 1 X-ray films displaying a fracture stem (left) and a nonfracture stem (right).

manuscripts, conference abstracts, and studies not directly studying the outcomes of fracture stems, or comparing the outcomes between fracture and nonfracture stems in the treatment of PHF were excluded. Two independent authors reviewed records from the initial search twice and excluded irrelevant ones. Titles and abstracts of remaining articles were then screened against the inclusion criteria. Included articles were critically reviewed according to a predefined data extraction form.

Data extraction

Extracted data parameters included details of study designs, publication year, patient numbers, basic demographics, functional outcomes, greater tuberosity healing prevalence, and complications. Functional outcomes extracted included the American Shoulder and Elbow Surgeons (ASES) score and Constant-Murley score as well as range of motion (ROM) in abduction, external rotation, and forward flexion. The prevalence of greater tuberosity healing was also recorded. Complications evaluated encompassed all-cause revisions, all infections, aseptic loosening, dislocations or instability, periprosthetic fractures, and scapular notching.

Methodology assessment

Methodology quality of included studies was assessed with the Methodological Index for Non-Randomized Studies (MINORS).[38] MINORS uses 12 criteria to assess nonrandomized comparative studies and 9 criteria for nonrandomized single-arm cohort studies. Each criterion was scored with a 3-point system from 0 to 2 (0: not reported, 1: inadequately reported, and 2: adequately reported). The ideal score for comparative studies is 24 points and that of noncomparative studies is 18 points.

Statistical analysis

Noncomparative meta-analysis was performed based on weighted pooled proportions (PP) and pooled weighted mean, whereas comparative meta-analysis was performed with odds ratio (OR) and weighted mean difference (MD) primarily used as summary statistics. In this meta-analysis, both fixed- and random-effects models were tested. The fixed-effects model assumed that treatment effects in each study were identical, whereas the random-effects model assumed that variations were present between studies. χ^2 tests were used to study heterogeneity between studies. I^2 statistic was used to estimate the percentage of total variation across studies, owing to heterogeneity rather than chance. Values greater than 50% were regarded as substantial heterogeneity. I^2 can be calculated as follows: $I^2 = 100\% \times (Q - df)/Q$. Q was defined as Cochrane's heterogeneity statistics and df defined as the degree of freedom. If substantial heterogeneity was present, the possible clinical and methodological reasons were explored qualitatively. This meta-analysis presented results with a random-effects model to account for clinical diversity and methodological variation between studies. All P values were 2-sided. OpenMetaAnalyst (Brown University, Providence, RI, USA, 2012) and Review Manager (version 5.3; The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark, 2014) were used for statistical analysis.

Results

Literature search

A selection process flowchart to include relevant studies is illustrated in Fig. 2. A total of 1138 studies were identified from the initial search, of which 456 duplicates and 112 non–English language articles were removed. Titles and abstracts of 570 remaining studies were screened according to the predefined inclusion criteria; 556 studies were excluded. Fourteen full-text articles were assessed for eligibility, and 2 additional articles[24,31] included after citation search. In total, 11 studies were included, including

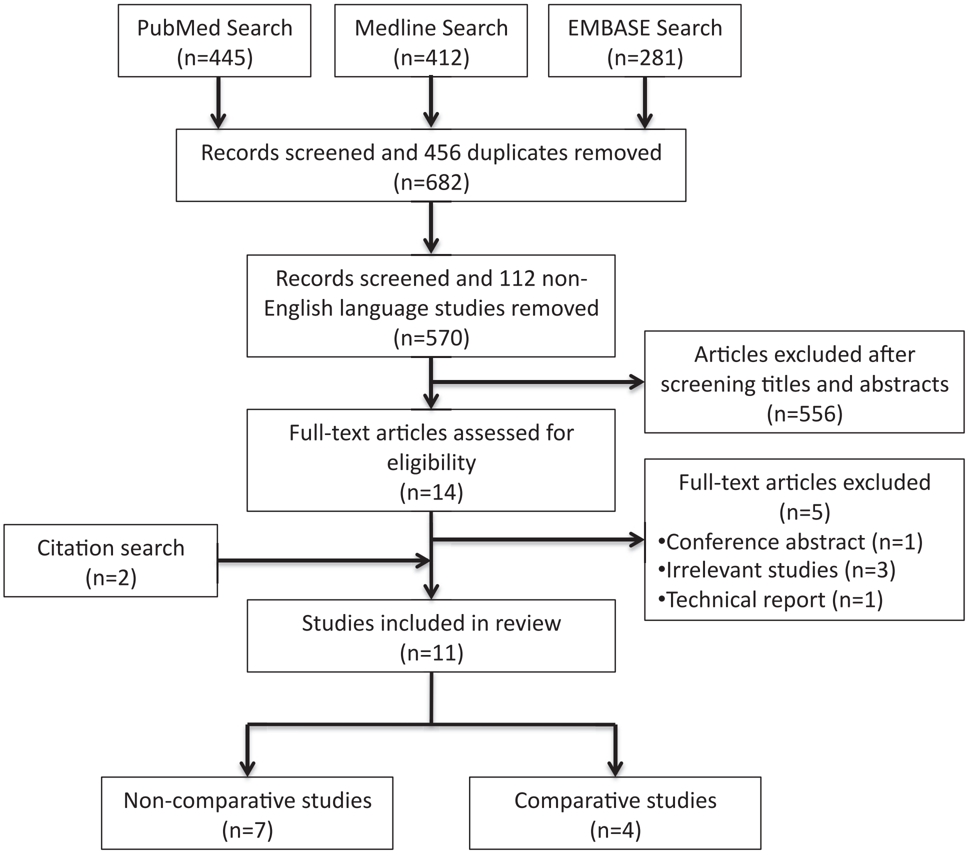

Figure 2 Preferred Reporting Items for Systematic reviews and Meta-Analyses selection process flowchart.

3 prospective[6,31,34] and 8 retrospective[4,5,14,22-25,36] studies. Seven studies[5,6,14,24,31,34,36] were noncomparative, whereas 4 studies[4,22,23,25] were comparative studies.

Methodology assessment

The aggregate MINORS score for included comparative studies ranged from 16[22] to 20,[23] with an average of 17.3. For noncomparative studies, the aggregate MINORS score ranged from 8[6] to 15,[36] with a mean of 12.9. Individual scores are detailed in Table I. It was noted that only 4 studies did not have any conflicts of interest.[14,22,24,34] One study was funded by a research grant,[23] whereas the remainder had a portion of authors receiving royalties (11 of 46) or paid consultancies (9 of 46) from the prosthesis manufacturer used in each individual study.[4-6,25,31,36] However, no correlation between surgeon conflict of interest and positive result could be identified, especially with the comparative analysis.

Stem designs

A variety of fracture-dedicated prostheses were used across studies. Aequalis (Tornier, Edina, MN, USA) and Humelock (Fx Solutions, Viriat, France) were 2 more common prostheses used, whereas one study used Comprehensive (Biomet, Warsaw, IN, USA) and another used Equinox (Exactech Inc., Gainesville, FL, USA). All prostheses were cemented with the exception of Humelock II. Suture loops were used for all of the tuberosities. The types and brands of prosthesis and tuberosity sutures are detailed in Table II.

Demographics

A total of 383 HA (294 fracture stems, 89 nonfracture stems) and 358 RTSA (309 fracture stems, 49 nonfracture stems) were included in this study. The mean age of patients ranged from 68[6] to 81.3[22] years and 73[25] to 77.6[23] years in the fracture and nonfracture stem groups, respectively. The mean time delay from injury to surgery was reported to range from a mean of 7[5] to 14[25] days and 8.7[23] to 16[25] days for the fracture and nonfracture groups, respectively. The deltopectoral approach was the preferred approach for surgery in both groups. The mean follow-up period ranged from 1.3[6] to 3.04 years,[22] with a minimum follow-up of 0.5 years[23] and a maximum of 8 years.[25] More details are depicted in Table I.

Table I MINORS score of individual studies

Article	Year	Clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to study aims	Unbiased assessment of endpoints	Follow-up period appropriate	Loss to follow-up less than 5%	Prospective calculation of study size	Adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analyses	Total
Boileau[4]	2013	2	2	2	2	1	2	0	0	2	0	1	2	16
Boileau[5]	2019	2	2	2	2	1	2	0	0	–	–	–	2	13
Boyer[6]	2017	1	2	2	1	0	1	0	0	–	–	–	1	8
Garofalo[14]	2015	2	2	2	2	2	2	0	0	–	–	–	2	14
Jeong[22]	2019	2	2	2	2	2	2	0	0	1	0	1	2	16
Jorge-Mora[23]	2019	2	2	2	2	2	2	0	0	2	2	2	2	20
Kontakis[24]	2009	2	2	2	2	1	2	0	0	–	–	–	1	12
Krishnan[25]	2011	2	2	2	2	1	2	0	0	2	0	2	2	17
Obert[31]	2016	2	2	2	2	1	2	2	0	–	–	–	1	14
Shah[34]	2011	2	2	2	2	2	2	1	0	–	–	–	1	14
Simovitch[36]	2019	2	2	2	2	1	2	2	0	–	–	–	2	15

MINORS, Methodological Index for Non-Randomized Studies.
2 = adequately reported, 1 = inadequately reported, 0 = not reported, "–" = not applicable.

Clinical outcomes

At the final follow-up, fracture stems show favorable clinical outcomes in terms of ASES score (mean = 74.0, 95% confidence interval [CI]: 69.3-78.7) and Constant-Murley score (mean = 65.8, 95% CI: 61.4-70.3) (Figs. 3 and 4, respectively) while restoring a considerable ROM in patients, including abduction (mean = 111°, 95% CI: 96°-125°), external rotation (mean = 29°, 95% CI: 25°-33°), and forward flexion (mean = 120°, 95% CI: 110°-130°) (Supplementary Appendix S1-S3, respectively). Fracture stems also led to high rates of greater tuberosity healing (PP = 0.806, 95% CI: 0.721-0.869) (Fig. 5).

Fracture vs. nonfracture stems

Fracture stems were found to have a significantly better ASES score (MD = 14.29, 95% CI: 8.18-20.41, $P < .001$), Constant-Murley score (MD = 7.96, 95% CI: 3.16-12.75, $P = .001$), external rotation (MD = 7°, 95% CI: 3°-10°, $P < .001$), forward flexion (MD = 17°, 95% CI: 10°-25°, $P < .001$), and greater tuberosity healing (OR = 2.75, 95% CI: 1.58-4.76, $P < .001$) than nonfracture stems at the final follow-up (Figs. 6-10, respectively). There was no statistically significant difference in abduction (MD = 4°, 95% CI: −11° to 20°, $P = .59$) (Supplementary Appendix S4).

Complications

There were few complications associated with the use of fracture stems. PP analysis of all-cause revision (PP = 0.041, 95% CI: 0.026-0.065), all infection (PP = 0.021, 95% CI: 0.012-0.037), aseptic loosening (PP = 0.010, 95% CI: 0.004-0.029), deep infection (PP = 0.018, 95% CI: 0.009-0.035), dislocation or instability (PP = 0.014, 95% CI: 0.006-0.031), nerve injuries (PP = 0.015, 95% CI: 0.006-0.036), periprosthetic fracture (PP = 0.024, 95% CI: 0.013-0.045), and superficial infection (PP = 0.014, 95% CI: 0.006-0.030) remained low. Scapular notching in RTSA patients with fracture stems (PP = 0.109, 95% CI: 0.028-0.343) also remained low (Supplementary Appendix S5-S13, respectively).

Fracture vs. nonfracture stems

Comparing fracture and nonfracture stems did not reveal any significant difference in terms of all-cause revision (OR = 1.25, 95% CI: 0.14-11.64, $P = .84$), deep infection (OR = 0.98, 95% CI: 0.19-5.20, $P = .98$), or periprosthetic fracture (OR = 0.55, 95% CI: 0.14-2.10, $P = .38$) (Supplementary Appendix S14-S16, respectively).

Table II Demographic details of included studies

Article	Year	Study design	Procedure	Number of shoulders			Mean age (yr)	Time to surgery (d)	Fracture pattern			Approach		Tuberosity fixation	Stem fixation type	Prosthesis	Manufacturer	Mean follow-up (yr)
				Males	Females	Total			2-Part	3-Part	4-Part	Deltopectoral	Superolateral					
Fracture stems																		
Boileau[4]	2013	Retrospective	Hemiarthroplasty	12	18	30	66	8.5	0	2	28	30	0	Ethibond suture loops	Cemented	Aequalis	Tornier	3.75
Boileau[5]	2019	Retrospective	rTSA	4	34	38	80	7	0	6	32	4	34	NiceLoops sutures (Tornier)	Cemented	Aequalis	Tornier	3
Boyer[6]	2017	Prospective	Hemiarthroplasty	–	–	69	68	7.1	0	134		118	16	SmartLoops sutures (Fx solutions)	Uncemented	Humelock II	Fx Solutions	2.08
Boyer[6]	2017	Prospective	rTSA	–	–	65	78		0							Humelock II	Fx Solutions	1.33
Garofalo[14]	2015	Retrospective	rTSA	25	62	97	76.2	–		97		97	0	Dacron sutures	Cemented	Aequalis	Tornier	2.25
Jeong[22]	2019	Retrospective	rTSA	2	18	20	81.3	–	2	7	11	20	0	Cerclage suture tension band	Cemented	Aequalis	Tornier	3.4
Jorge-Mora[23]	2019	Retrospective	rTSA	3	31	34	76.5	7.8	0	34		32	2	Osteosuture	Uncemented	Humelock II	Fx Solutions	2.17
Kontakis[24]	2009	Retrospective	Hemiarthroplasty	5	23	28	66.4	5.14	0	6	22	28	0	Ethibond suture loops	Cemented	Aequalis	Tornier	3.28
Krishnan[25]	2011	Retrospective	Hemiarthroplasty	20	92	112	72	14	0	5	107	–	–	Cerclage suture tension band	Cemented	Aequalis	Tornier	2.67
Obert[31]	2016	Prospective	Hemiarthroplasty	4	19	23	67.3	7.1	0	4	19	23	0	SmartLoops sutures (Fx solutions)	Uncemented	Humelock II	Fx Solutions	4.28
Shah[34]	2011	Prospective	Hemiarthroplasty	8	24	32	72.3	–	0	4	28	32	0	Orthocord (DePuy Mitek)	Cemented	Comprehensive	Biomet	2.11
Simovitch[36]	2019	Retrospective	rTSA	17	38	55	77	–		55		55	0	Cerclage suture tension band	Cemented	Equinoxe	Exactech Inc.	2.81
Nonfracture stems																		
Boileau[4]	2013	Retrospective	Hemiarthroplasty	11	20	31	67	7.5	0	2	29	31	0	Ethibond suture loops	Cemented	Aequalis	Tornier	6.75
Jeong[22]	2019	Retrospective	rTSA	6	19	25	77	–	2	9	14	25	0	Cerclage suture tension band	Cemented	Aequalis	Tornier	3.4
Jorge-Mora[23]	2019	Retrospective	rTSA	0	24	24	77.6	8.7	0	24		22	2	Osteosuture	Cemented	Arrow	FH Ortho	2.17
Krishnan[25]	2011	Retrospective	Hemiarthroplasty	16	42	58	73	16	0	53	5	–	–	Cerclage suture tension band	Cemented	Select	Zimmer	2.67

rTSA, reverse total shoulder arthroplasty.
"–" = data not available.
The Aequalis fracture stems uses a low-profile proximal body and open neck for bone grafting and for anatomic positioning of tuberosities. The polished medial neck reduces suture abrasion and wear, allowing longer stability of tuberosity reconstruction for healing to occur. Comprehensive fracture stems adopt a reverse Morse taper for improved glenoid access, hashmarks for proper reproduction of humeral height, with lateral or medial fins with contoured suture holes for reduction in suture wear and optimal tuberosity fixation. Its smaller proximal body and 45° neck angle also allows for easier tuberosity reconstruction. Equinox fracture stems use a patented anterior-lateral fin and asymmetric tuberosity beds that act as scaffolding to allow accurate positioning of the tuberosities for optimal healing. Humelock II is a cementless prosthesis with diaphyseal cross-bolts to provide rotational stability. Its proximal anchoring plate and offset modular system provides the means to anatomically reconstruct the tuberosities.

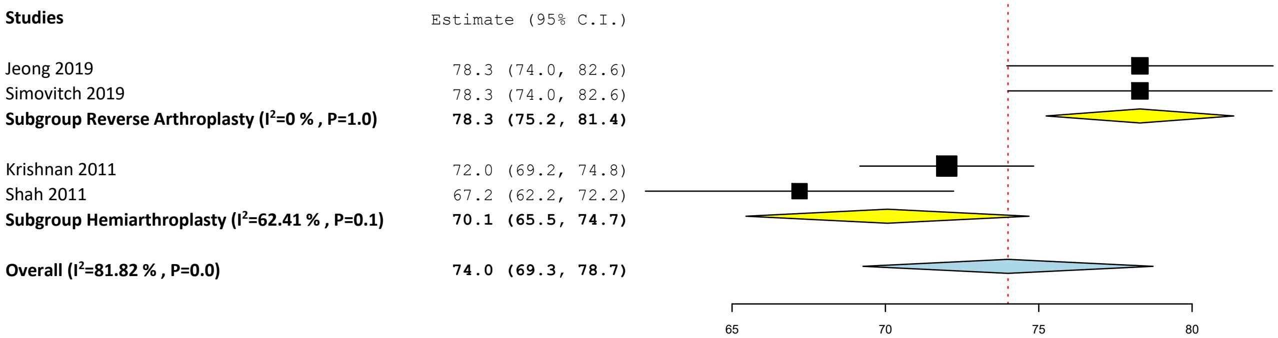

Figure 3 Pooled weighted analysis of American Shoulder and Elbow Surgeons (ASES) score in fracture stems. *CI*, confidence interval.

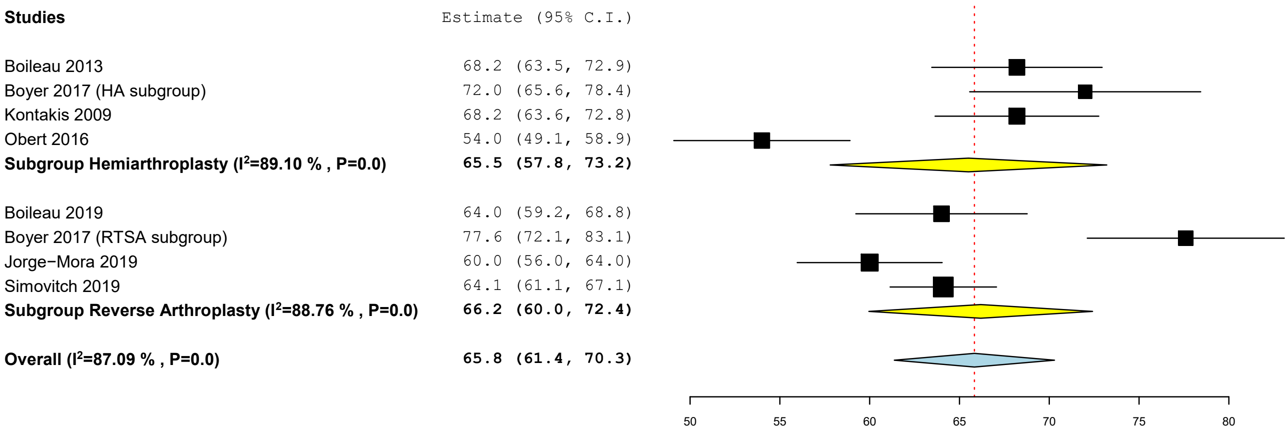

Figure 4 Pooled weighted analysis of Constant-Murley score in fracture stems. *CI*, confidence interval.

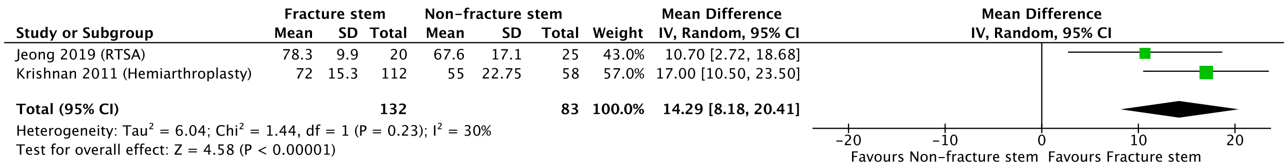

Figure 5 Comparative meta-analysis of American Shoulder and Elbow Surgeons (ASES) score between fracture (n = 132) and non-fracture stems (n = 83). *CI*, confidence interval; *SD*, standard deviation.

Discussion

Our analysis revealed that fracture stems are associated with good patient-reported outcome measures, shoulder joint ROM, high prevalence of greater tuberosity healing, and minimal complications with a minimum follow-up of 0.5 years in HA or RTSA for treating PHF. Compared with nonfracture stems, fracture stems exhibit a statistically significant superiority in patient-reported outcome measures, shoulder joint ROM, and greater tuberosity healing. The weighted mean differences in ASES and Constant-Murley scores between fracture and nonfracture stems were greater than the minimum clinically important difference.[35] Greater tuberosity healing was also 2.75 times more likely with the use of fracture stems in HA or RTSA, which may lead to more consistent and predictable clinical outcomes.

Fracture stems are usually specifically designed for better healing of the tuberosities and proximal bone defect in 3- to 4-part PHF. The healing of the greater tuberosity is generally considered important in allowing patients to regain ROM of the shoulder joint and independence for activities of daily living, especially if injury is on the dominant side.[9,13,18,19,31] This is supported by studies

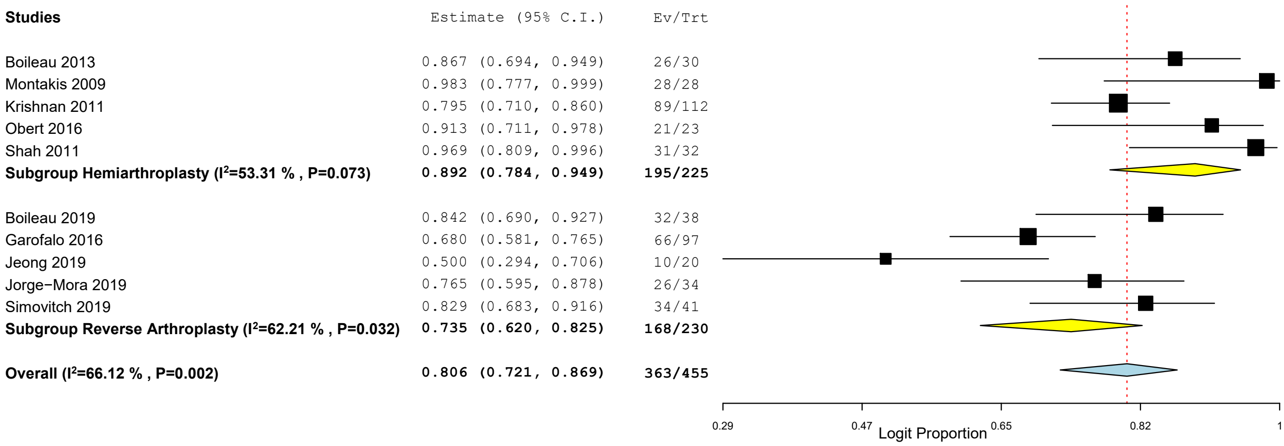

Figure 6 Pooled weighted analysis of greater tuberosity healing in fracture stems. *CI*, confidence interval.

Study or Subgroup	Fracture stem Mean	SD	Total	Non-fracture stem Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Boileau 2013 (Hemiarthroplasty)	68.2	13.25	30	58.9	16.25	31	41.6%	9.30 [1.87, 16.73]
Jorge-Mora 2019 (RTSA)	60	12	34	53	12	24	58.4%	7.00 [0.73, 13.27]
Total (95% CI)			**64**			**55**	**100.0%**	**7.96 [3.16, 12.75]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.21$, df = 1 (P = 0.64); $I^2 = 0\%$
Test for overall effect: Z = 3.25 (P = 0.001)

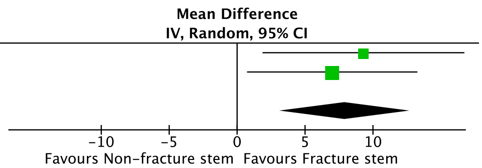

Figure 7 Comparative meta-analysis of Constant-Murley score between fracture (n = 64) and nonfracture (n = 55) stems. *CI*, confidence interval; *SD*, standard deviation.

Study or Subgroup	Fracture stem Mean	SD	Total	Non-fracture stem Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Boileau 2013 (Hemiarthroplasty)	34	15	30	23	15	31	18.8%	11.00 [3.47, 18.53]
Jeong 2019 (RTSA)	25	14	20	22	17	25	13.0%	3.00 [-6.06, 12.06]
Jorge-Mora 2019 (RTSA)	23	13	34	17	12	24	25.3%	6.00 [-0.49, 12.49]
Krishnan 2011 (Hemiarthroplasty)	39	11.67	112	33	17.5	58	42.8%	6.00 [1.00, 11.00]
Total (95% CI)			**196**			**138**	**100.0%**	**6.55 [3.28, 9.82]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 2.01$, df = 3 (P = 0.57); $I^2 = 0\%$
Test for overall effect: Z = 3.93 (P < 0.0001)

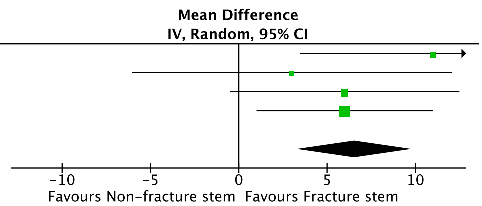

Figure 8 Comparative meta-analysis of range of shoulder external rotation between fracture (n = 196) and nonfracture (n = 138) stems. *CI*, confidence interval; *SD*, standard deviation.

demonstrating a significantly better overall Constant-Murley score between patients with and without consolidated tuberosities.[4,23] Furthermore, the difference in Constant score between the healed and malunited tuberosity groups was higher than the minimum clinically important difference of 5.7 for patients undergoing shoulder arthroplasty.[35] Hence, tuberosity reconstruction appears to be important, and a dedicated fracture stem when performing arthroplasty in the PHF setting would likely help achieve this goal.[4,22,23,25]

Surgical technique must focus on anatomic reduction and reconstruction of tuberosities, which can be technically demanding.[2] Malposition or migration of tuberosities has been identified as one of the most important determinants of unsatisfactory results.[3] Loss of fixation of the tuberosities can cause the rotator cuff to be trapped under the acromion leading to impingement syndromes or even cuff tears and superior migration of the humeral head. Jeong et al[22] also raised concerns and reported 2 cases of aseptic loosening and subsequent periprosthetic fracture of the humerus due to secondary tuberosity failure and heterotopic ossification. Retroversion and height of stem placement are also important factors.[2,3] Retroversion is important for stability of shoulder joint. Stems in an abnormally high position may lead to malposition, nonunion, and secondary migration of tuberosities,[21] whereas stems in an abnormally low position may lead to loss of deltoid power.[3,21]

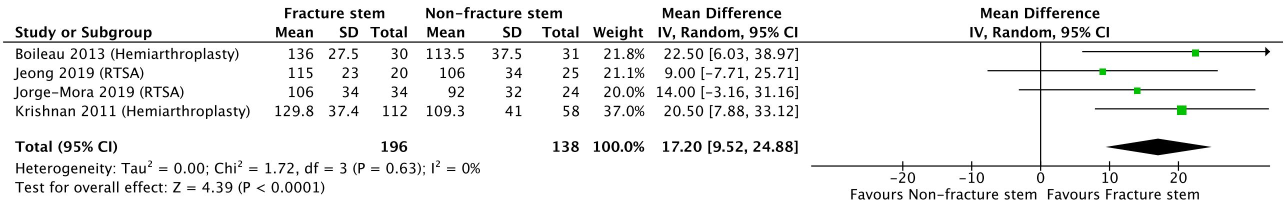

Figure 9 Comparative meta-analysis of range of shoulder forward flexion between fracture (n = 196) and nonfracture (n = 138) stems. *CI*, confidence interval; *SD*, standard deviation.

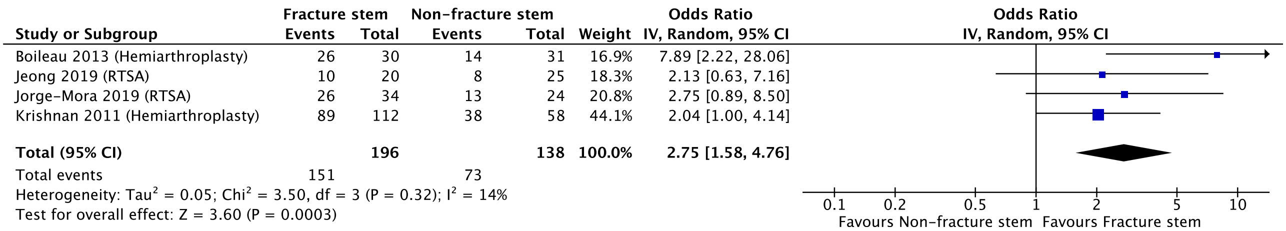

Figure 10 Comparative meta-analysis of greater tuberosity healing between fracture (n = 196) and nonfracture (n = 138) stems. *CI*, confidence interval.

In additional to using a nonfracture stem, Boileau et al[4] reported that there are several risk factors contributing to greater tuberosity nonunion, including patient age (≥75 years) and female sex. Patient age and female sex are likely associated with poorer bone quality with reduced capacity for bone healing. When comparing between patients older and younger than 60 years of age, Obert et al[31] reported no statistically significant difference. Garofalo et al[14] also reported seeing greater tuberosity nonunion only in females at a rate of 33.8%.

HA was the first arthroplasty option used in PHF that were considered not fixable. However, the technical difficulty and high dependence of clinical outcomes on the fate of tuberosity healing meant functional outcomes were inconsistent.[3,19] RTSA was originally introduced for the indication of rotator cuff arthropathy, but has been increasingly used as an option in PHF.[10,22,27] The main advantage of RTSA over HA is relatively reduced dependence on cuff healing.[15] A recent systematic review comparing RTSA vs. HA for PHF concluded that RTSA is an acceptable alternative surgical option. The study found that despite significantly better forward flexion in RTSA, there was no significant clinical difference in ASES score or Constant score between RTSA and HA.[11] In terms of complications, RTSA was associated with fewer revisions, but slightly more clinical complications in the short to medium term than HA.[11]

Limitations

Limitations of this study include the lack of randomization and prospectively followed-up patient, which means that recall and selection bias cannot be excluded. There was also significant heterogeneity in terms of surgical technique, prosthesis brand, stem fixation type, greater tuberosity repair technique, and follow-up period. Confounding factors such as premorbid comorbidities, size of tuberosity fragments, and the quality of reduction or presence of rotator cuff tendinopathies or tears associated with the initial injury could not be adjusted for as these were not available from individual articles. Analysis of revisions solely indicated by aseptic loosening or malunion of greater tuberosity was also not available for comparison.

Conclusion

Treatment of PHF with fracture stems, either in the setting of RTSA or HA, shows overall favorable clinical outcomes with low complication rates. There is increasing evidence to suggest the superiority of fracture stems over nonfracture stems in clinical outcomes, both for RTSA and HA, while maintaining similar complication rates.

Disclaimer

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2020.09.044.

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